FUEL CELL SYSTEM AND METHOD FOR GENERATING ELECTRICAL ENERGY USING A FUEL CELL SYSTEM

A1>

The present invention relates to a fuel-cell system Particularly ~~according to the definition of the species in Claim 1, especially~~ a drive system of a motor vehicle, having a reformer unit for producing hydrogen from a raw material, Such as, for example ~~especially~~ a liquid raw material, while feeding in air, in order to operate a downstream fuel-cell unit; An ~~an~~ oxidation device for converting carbon monoxide into carbon dioxide is ~~being~~ located between the reformer unit and the fuel-cell unit. In addition, the present invention relates to a method ~~processes~~ for generating electrical energy, using a fuel-cell system, Particularly ~~especially~~ for a drive system of a motor vehicle; Hydrogen is ~~hydrogen being~~ produced from a raw material, in a reforming process, as air is fed in, in order to operate a fuel-cell unit; Carbon ~~and carbon~~ monoxide is ~~being~~ oxidized to carbon dioxide after the reforming process, and in front of the fuel-cell unit. ~~, in accordance with the first part of Claim 10.~~

A2>

A catalytic hydrogen generator is known from EP 0 217 532, which produces hydrogen from a methanol-air mixture in an autothermal reformer unit. Located in the reformer unit is a thermocouple, which controls the supply of air to the methanol-air mixture so ~~in such a manner~~, that the air supply is reduced as the temperature increases at the location of the thermocouple in the reformer.

International Published Patent Application No. ~~In a further development of this system~~, WO 96/00186 describes a hydrogen generator, the catalyst being positioned around an inlet pipe for the methanol-air mixture, so ~~in such a manner,~~ that the methanol-air mixture flows radially through the catalyst.

~~DE~~ 43 45 319 ~~C2~~ and ~~DE~~ 43 29 323 each ~~C2~~ describe a fuel-cell current-generating system, in which hydrogen is produced from a methanol-water mixture in a reformer unit. The ~~This~~ hydrogen is supplied to a downstream fuel cell for generating electrical energy. To generate a sufficient amount of heat for the reaction in the reformer, a portion of the methanol is not added to the methanol-water mixture~~,~~ but is rather combusted in an additional burner.

An electric vehicle having a driving battery made of fuel cells is ~~known from DE~~ 196 29 084 A1, the fuel cells being arranged so ~~in~~ such ~~a manner,~~ that they are cooled by the wind from driving.

In the article "Heureka?" in DE-Z Autotechnik No. 5/1997, on pages 20 to 21 ~~20/21,~~ a motor vehicle having a fuel-cell drive is described, where the hydrogen necessary for operating the fuel cells in the vehicle is ~~even~~ obtained from gasoline. In this arrangement ~~case~~, the gasoline is converted into hydrogen in a multi-step process. Prior to conversion, the gasoline is converted ~~brought~~ into the gaseous state by heating it in an evaporator. Hydrogen and carbon monoxide are formed in a partial-combustion reactor, under oxygen-deficient conditions. Copper-oxide and zinc-oxide catalysts are provided for oxidizing the carbon monoxide, and steam is ~~being~~ used to supply oxygen for the reaction. In a further step, a final carbon monoxide fraction of, approximately 1% is subsequently burned in a conventional platinum oxidation catalyst. The mixture of hydrogen, carbon monoxide, and carbon dioxide obtained in this manner still contains 10 ppm carbon monoxide, which is not harmful to a downstream fuel cell. After being cooled down to approximately 80 degrees Celsius in a heat exchanger, the gas is supplied ~~lead from there~~ into the fuel cell.

A similar fuel-cell system for motor vehicles is described in ~~known from~~ the article "Alternative Fuel" appearing in the Japanese periodical, Asia-Pacific Automotive Report, 1/20/98, Vol. 272, page 34

to ~~through~~ 39, where a methanol reformer unit is provided to produce hydrogen for a fuel cell. In this arrangement ~~case~~, water produced in the electrochemical reaction of hydrogen and oxygen is reused for the reforming process. For the reforming process, deionized water and methanol are mixed, evaporated, and converted into hydrogen and carbon dioxide at a temperature of 250 degrees Celsius. The ~~This~~ hydrogen is supplied to a fuel cell, which, in a catalytic process, converts the hydrogen, together with atmospheric oxygen, into electrical energy and water. The heat energy necessary for the evaporation and for the reforming process is produced in a catalytic burner, which is located downstream from the fuel cell, and is run by residual gas from the fuel cell. This gas contains hydrogen, since the fuel-cell system only utilizes approximately 75% of the supplied hydrogen. If no ~~not enough~~ residual hydrogen is available for the catalytic burner, methanol from the fuel tank is used to generate heat for the reformer. Before introducing the gas produced in the reformer, of which a portion is hydrogen, this gas is purified by a catalytic reaction, in which carbon monoxide is converted into carbon dioxide. In One ~~a represented specific~~ embodiment of a fuel-cell system for a motor vehicle, the methanol reformer includes an evaporator, a reformer, and an oxidation unit for carbon monoxide.

~~DE~~ 43 22 765 C1 describes a method and a device for dynamically controlling the power output for a vehicle having a fuel cell, which supplies electrical energy to an electrical drive unit. Starting from a power requirement corresponding to the position of an accelerator pedal, a mass flowrate of air is calculated, which is needed by ~~on the part of~~ the fuel cell to provide a corresponding, desired power output. The speed of a compressor positioned in an intake line of the fuel cell is controlled as a function of the required air flow rate.

A method and a device for supplying air to a fuel-cell system is ~~known from EP~~ 0 629 013 ~~B1~~. In this arrangement ~~case~~, process air is compressed by a compressor, before it enters a corresponding

fuel cell. After process air flows through the fuel cell, the removed exhaust air is expanded over a turbine, in order to recover energy~~; the~~ the turbine, the compressor, and an additional driving motor are ~~being~~ arranged on a common shaft. The compressor is designed to have a variable speed, and is arranged, along with an expander in the form of a turbine, on a common shaft, in order to expand the exhaust air. The air flow rate for the fuel cell is controlled by using an expander having a variable absorption capacity.

A screw-type compressor for a refrigerator is ~~known from~~ WO 97/16648. The ~~This~~ screw-type compressor includes two pump chambers, an outlet of a first pump chamber being connected to a secondary inlet of a second pump chamber.

The present invention is based on the object of Providing ~~further developing~~ a fuel-cell system ~~of the type mentioned above, in such a manner,~~ that ~~it~~ can be used more economically~~,~~ and in an environmentally friendlier manner, to generate electrical energy, Particulary ~~especially~~ for a drive system of a motor vehicle, while operating at high efficiency and occupying a small space.

The ~~object~~ of the present invention are ~~is~~ achieved by Providing a fuel-cell system ~~of the type mentioned above, having the features~~ indicated in Claim 1, and by a process of the type mentioned above, having the features indicated in Claim 10. Advantageous refinements of the present invention are specified in the dependent claims.

The ~~To that end, the~~ present invention provides for a fuel-cell system having a water-injection device at the oxidation device, the water-injection device injecting water into the oxidation device.

This arrangement has the advantage that, simultaneously to removing carbon monoxide from a process gas, which is from the reformer unit

and has a high concentration of hydrogen for the fuel-cell unit, the process gas is sufficiently cooled or precooled, so that it can be directed to the fuel-cell unit without an expensive cooling device, or by using a correspondingly less expensive cooling device. In addition, the injected water ~~also~~ supplies oxygen necessary to oxidize carbon monoxide, this oxidation reaction simultaneously releasing hydrogen ~~as well~~, so that the amount of oxygen having to be separately supplied to the oxidation device can be reduced, and at the same time, the concentration of hydrogen in the process gas can be increased. At the same power output, the additional hydrogen enrichment in the oxidation device allows the fuel-cell system to be dimensioned smaller, ~~This~~ thereby correspondingly ~~reduces~~ reducing the required space ~~as well as~~ and the cost of equipment for the fuel-cell system.

In ~~a preferred~~ one embodiment, the reformer unit ~~has~~ includes a mixer for the raw material, and an oxygen-containing substance, ~~especially~~ water and/or air.

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A closed water cycle ~~can~~ may be attained without having to ~~carry along~~ transport large amounts of water for the reforming process, in that a water-separation device, ~~especially~~ such as, for example a condenser, is provided in an exhaust-gas stream from a cathode of the fuel-cell unit, and/or in an exhaust-gas stream from an anode of the fuel-cell unit; ~~the~~ The condenser ~~removing~~ removes the water contained in the corresponding exhaust gas, and ~~feeding~~ supplies it to a water storage device connected upstream from the autothermal reformer unit.

An ~~advantageous~~ embodiment, 913 provides a separate water cycle, which cools the water-separation devices, the fuel-cell unit, the air supplied to a cathode of the fuel-cell unit, and/or the air supplied to the reformer unit. To generate the appropriate heat energy necessary for the reaction in the reformer unit, a catalytic burner is provided, which combusts exhaust gas from an anode of the fuel-cell unit, and directs

the corresponding waste heat through a heat exchanger, to the reformer unit.

Alternatively, heat may ~~can~~ be generated for the reformer unit by connecting the catalytic burner to a storage tank for the raw material.

Energy may ~~can~~ be recovered by providing an expander in a cathode-exhaust stream of the fuel-cell unit, and by providing a compressor, such as, for example ~~particularly~~ a two-stage compressor, in a supply-air stream of the fuel-cell unit, the expander and compressor being arranged on a common shaft.

Such a two-stage compressor further increases the environmental compatibility and the efficiency of the fuel-cell system, in that two tappable pressure stages provide the rest of the system with different levels of air pressure. The cathode of the fuel-cell unit is subjected to a relatively low pressure by a first stage, while a second stage initially feeds air at a higher pressure to the reformer unit. ~~, and~~ Because ~~because~~ of its higher relative pressure level, the second stage compensates for the pressure losses occurring along the longer path, to the extent that approximately the same pressure is applied to the anode and cathode sides of the fuel-cell unit.

The raw material may include ~~is advantageously~~ a substance containing hydrogen, such as, for example ~~especially~~ methanol or gasoline.

In the method according to ~~a process of the type mentioned above~~, the present invention, ~~provides for~~ water is ~~being~~ injected during the oxidation of carbon monoxide to carbon dioxide.

This has the advantage that, simultaneously to removing carbon monoxide from a process gas, which is from the reforming process and has a high concentration of hydrogen for the fuel-cell unit, the process gas is sufficiently cooled or

precooled, so that it can be directed to the fuel-cell unit without an expensive cooling device~~,~~ or by using a correspondingly less expensive cooling device. In addition, the injected water also supplies the oxygen necessary to oxidize carbon monoxide, this oxidation reaction simultaneously releasing hydrogen ~~as well~~, so that the amount of oxygen having to be supplied separately to the oxidation device can be reduced, and at the same time, the concentration of hydrogen in the process gas is increased. At the same power output, the additional hydrogen enrichment in the oxidation device allows the fuel-cell system to be dimensioned smaller~~.~~ thereby ~~This~~ correspondingly Reducing ~~reduces~~ the required space~~,~~ as well as the cost of equipment for the fuel-cell system.

In order for the supply water to achieve a high efficiency, it may be ~~is~~ injected in the form of a vapor or aerosol.

An additional increase in the efficiency of the fuel-cell unit MAY ~~can~~ be attained by supplying compressed air to a process gas~~,~~ between the carbon monoxide oxidation and the fuel-cell unit and/or to a cathode of the fuel-cell unit.

A closed water cycle MAY ~~can~~ be attained without having to tRANSPORT ~~carry along~~ large amounts of water for the reforming process, by removing water from a cathode exhaust stream of the fuel-cell unit and/or from an anode exhaust stream of the fuel-cell unit~~,~~ and supplying it to the reforming process.

To generate the appropriate heat energy necessary for the reaction of the reforming process, an exhaust gas from an anode of the fuel-cell unit is burned, and the corresponding waste heat is supplied to the reforming process.

Alternatively, heat may ~~can~~ be generated for the reformer unit by burning a raw material and supplying the corresponding heat energy to the reforming process.

A hydrogen-containing substance, such as, for example ~~especially~~ methanol or gasoline, may be ~~is advantageously~~ used as a raw material.

~~Additional features, advantages, and advantageous refinements of the present invention proceed from the dependent claims, as well as from the following description of the present invention in light of the included drawing. This shows a block diagram of a preferred embodiment of a fuel-cell system according to the present invention.~~

In the ~~this~~ fuel-cell system, hydrogen for a fuel-cell unit 10 having an anode 12, a cathode 14, and a cooling element 16 is produced by an autothermal reformer unit 18, which includes a mixer 20, a heat exchanger 22, an evaporator 24, and a catalytic reformer 26. To produce hydrogen, a raw material, such as, for example ~~e.g.~~ methanol from a methanol tank 28, and water from a water tank 30 are supplied to mixer 20. The mixture of methanol and water is evaporated in evaporator 24, and a process gas in the form of a crude gas 32, which has a high fraction of hydrogen, is generated in a catalytic reaction in catalytic reformer 26.

The ~~This~~ crude gas contains, inter alia, carbon monoxide (CO), which must be removed before supplying ~~feeding~~ it into fuel-cell unit 10. Crude ~~To this end, crude~~ gas 32 is directed into an oxidation unit 34, in which ~~where~~ carbon monoxide is oxidized to carbon dioxide (CO_2) in the presence of air supplied by line 36, so that a CO concentration of less than 20 ppm results. At the same time, water from water tank 30 is supplied via a line 44, the supplied water being injected into oxidation unit 34 by an injection device 46. This simultaneously cools the process gas in oxidation unit 34. In an anode-gas condenser 40, the cleaned gas 38 produced and cooled in this manner has water removed from it, which is supplied ~~fed~~ back to water tank 30 via line 42. Cleaned gas 38 having a high concentration of hydrogen is then directed into anode 12 of fuel-cell unit 10. For example, cleaned gas 38 contains 50% H_2, 25% N_2, and 25% CO_2 at a temperature of approximately 180 to 200 degrees Celsius.

Before being directed into anode 12, ~~it~~ cleaned gas 38 is cooled down, ~~e.g.~~ for example to approximately 85 degrees Celsius~~,~~ in anode-gas condenser 40.

On cathode side 14, compressed air from a two-stage, screw-type compressor 50 is supplied via line 48 to fuel-cell unit 10. All of the air lines are indicated by dotted lines in ~~the figure~~ figure 1. Thus, the fuel-cell unit generates electrical energy in a ~~known~~ conventional manner~~,~~ by the reaction

$$H_2 + ½ O_2 \rightarrow H_2O + \text{el. energy}.$$

~~This~~ The electrical energy can be tapped off at electrodes 12, 14~~,~~ and supplied to an electric motor 52. Two-stage, screw-type compressor 50 includes a first stage 54 having a pressure of, ~~e.g. ca.~~ 3 bar for cathode 14; and a second stage 56 having a pressure of, ~~e.g.~~ for example 3.7 bar for the fuel gas, i.e.~~,~~ dehydrated, cleaned gas 38, to be supplied to anode 12. Using another tap on screw-type compressor 50, compressed air is ~~fed~~ supplied via line 58 to cleaned gas 38, downstream from anode-gas condenser 40.

A water separator 62, ~~which~~ separates water from anode gas 60 and supplies it via line 64 to water tank 30. ~~In~~ Disposed in cathode exhaust stream 66 is a condenser 68, which removes water from cathode gas 66 and supplies it via line 70 to water tank 30. A closed water circulation loop for the process gas is thus formed ~~in this manner~~, so that large amounts of water do not have to be ~~carried along~~ transported for the production of hydrogen in reformer unit 18.

A separate water circulation loop 72 indicated by a wavy line in figure 1 is provided to cool the air supplied to mixer 20, to cool anode gas condenser 40, water separator 62, and condenser 68, and to cool the air 48 supplied to cathode 14. This separate water circulation loop 72 includes a cooling-water tank 74, a deionized water tank 76, and corresponding heat exchangers 78

and 80 at cathode 14 air supply 48 and mixer 20 air supply, respectively.

Anode exhaust stream 60 flows into catalytic burner 82, in which anode gas 60 is further combusted to form heat energy. This heat energy is ~~passed on~~ transferred by heat exchanger 22 to evaporator 24 and catalytic reformer 26, where it sustains the catalytic reaction for producing hydrogen. Air is supplied to catalytic burner 82 by line 84. Downstream from catalytic burner 82, water from water tank 30 ~~can~~ may optionally be ~~fed~~ supplied to anode gas 60 by line 86. Alternatively, methanol from methanol tank 28 ~~can~~ may be supplied by line 88 to catalytic burner 82, so that even in the case of an insufficient anode exhaust stream 60, ~~e.g.~~ for example during start-up of the fuel-cell system, it is ensured that a sufficient amount of heat energy is generated the reformer unit 18.

Cathode exhaust stream 66 is cooled in a heat exchanger 90 of separate water circulation loop 72, and is then thermally coupled, via heat exchanger 92, to anode exhaust stream 60, before both exhaust streams 60 and 66 exit the system.

In this ~~case~~ arrangement, cathode exhaust stream 66 is directed through an expansion turbine 94 that is positioned, together with a compressor 96 for drawing in air 98, on a common shaft 100. ~~the~~ The compressor ~~being~~ is provided as an input stage, in front of two-stage compressor 50. ~~By this means~~ Thus, energy contained in cathode exhaust stream 66 is recovered, in order to compress air 98 in compressor 96.

A particular advantage of this ~~specific~~ embodiment, which is characterized by a high efficiency, a small space requirement, and a low equipment cost, is achieved by combining two-stage compressor 50 and autothermal reformer unit 18 with the additional injection 46 of cooling water during the selective oxidation of carbon monoxide (CO) in oxidation unit 34, and by

combining this with an autonomous water circulation loop 30, 40, 42, 62, 64, 68, 70.